3. Wastewater Constituents

Wastewater chemistry and physical characteristics are important factors in the design, operation and management of wastewater land application systems. The following sections discuss sources and types of wastewater, and their physical, chemical, and biological properties.

3.1 Sources of Wastewater

Wastewater is normally classified as coming from domestic sources or industrial sources:

- The most common source of wastewater is domestic wastewater. Sanitary (domestic) wastewater comes primarily from residences, non-industrial businesses, and institutional sources. Some examples of sanitary wastewater are restroom, laundry, and kitchen waste. Sanitary wastewater tends to be fairly uniform in composition, and is composed of approximately 99.94% water and 0.06% waste constituents.
- Industrial wastewater is discharged from industrial facilities and some heavy commercial operations. Industrial wastewater characteristics change with changing production rates and schedules, and it is much more variable than sanitary wastewater, possibly containing toxic substances, such as metals. Possible concerns with the land application of high strength industrial wastewater include odor and overloading of the site with constituents (waste elements) in the wastewater stream. These systems typically require additional pretreatment and/or special site management practices to provide good performance. Regulatory definitions of municipal reclaimed wastewater classes can be found in the Rules for the Reclamation and Reuse of Municipal and Industrial Wastewater (IDAPA 58.01.17)

3.2 Types of Wastewater

Wastewater contains two primary types of waste: organic and inorganic.

- Organic wastes originate from plant or animal sources and can generally be consumed by bacteria and other organisms. All organic wastes contain carbon.
- Inorganic wastes come from mineral materials, such as sand, salt, iron and calcium, and these wastes are only slightly affected by biological activity.

The source of wastewater influences the amount of organic and inorganic waste in a particular waste stream. For example, wastewater from a meat processing plant will contain high levels of organic waste, while wastewater from a gravel washing operation will contain high levels of inorganic waste.

Two other types of waste are thermal and radioactive wastes. Thermal power stations and industrial cooling processes may produce wastewater with temperatures exceeding the requirements of the enforcing agency. Hospitals, research labs, and nuclear power plants generate radioactive wastes that are usually controlled at their source.

3.3 Wastewater Physical Characteristics

Physical characteristics of wastewater include color, odor, temperature, and the levels of solids present. Changes in these physical characteristics can indicate unusual influent (wastewater entering a treatment system) or operating conditions.

3.3.1 Color

Raw wastewater (prior to any pretreatment and land application) is usually gray in color. Pretreated wastewater will have a color that is indicative of the pretreatment system: wastewater treated in a septic tank will have a gray/black color, but wastewater that has been treated in an aerobic process will have little color. The color of wastewater can also be affected by industrial contributions to the treatment system: color contributed by industry typically is not removed by the pretreatment system.

3.3.2 Odor

Raw wastewater usually produces a musty odor, generally caused by the anaerobic decomposition of organic material. Hydrogen sulfide is frequently the source of a rotten-egg odor in wastewater. Other volatile sulfur-containing compounds, such as mercaptans, can also cause noxious odors. These odors are released into the air when wastewater is aerated and sometimes when the wastewater is discharged to a land application site.

Unusual odors, such as petroleum or solvent odors, may indicate abnormal industrial discharges.

3.3.3 Temperature

Wastewater is generally somewhat warmer than tap water. A significant increase in wastewater temperature over a short period of time may indicate an unusual industrial discharge, while a significant decrease may indicate an influx of storm water into the treatment system.

Temperature is an important factor in microbial activity. Up to a point, an increase in wastewater temperature will increase microbial activity. However, when wastewater reaches high temperatures, microbial activity will be inhibited.

During land application of wastewater, high wastewater temperatures can also adversely impact cover crops.

3.3.4 Solids

One of the primary functions of a wastewater pretreatment system is the removal of solids from wastewater. If the level of solids is not significantly reduced by pretreatment, these materials can reduce the effectiveness of disinfection systems and clog land application equipment.

Determination of the forms and concentrations of solids present in wastewater can provide an operator with useful data for the control of treatment processes. Solids are divided into several different fractions: total solids, dissolved solids and suspended solids, as shown in Figure 3-1.

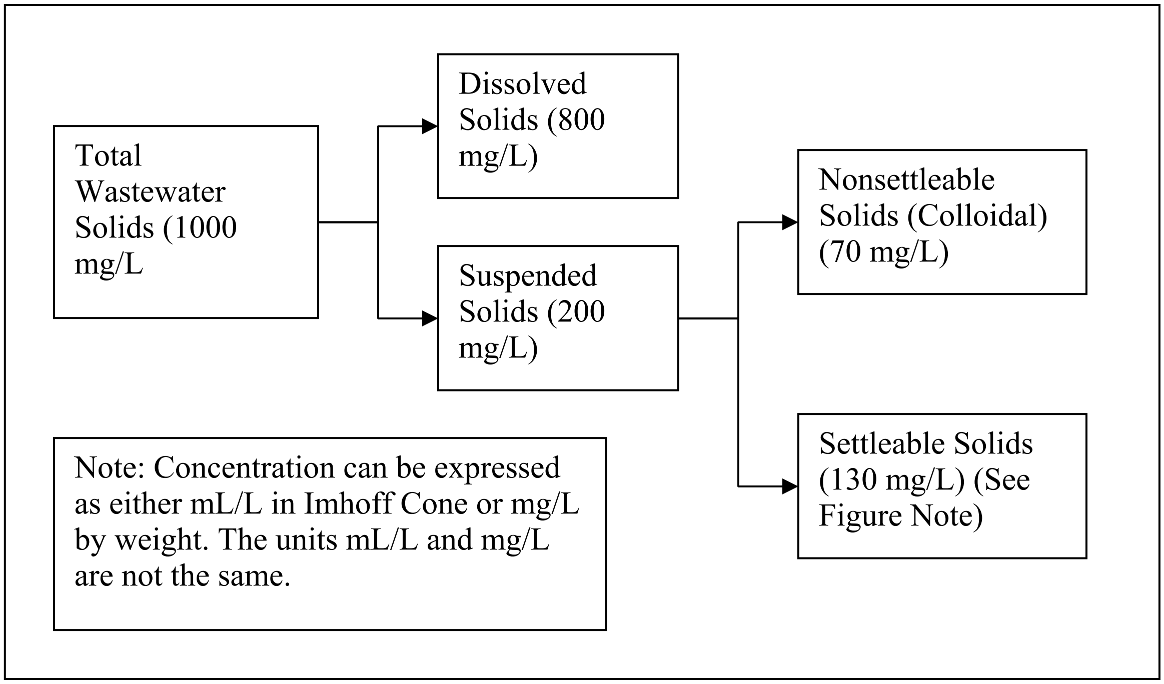

Figure 3-1. Typical composition of solids in raw wastewater (Adapted from EPA 2004).

3.3.4.1 Total Solids (Residue)

Total solids are the amount of material that remains after the wastewater is evaporated at a temperature of 103°C to 105°C. Total solids consist of both dissolved solids and suspended solids. Suspended solids consist of both settleable and nonsettleable solids. See Figure 3-1. Total solids is determined by taking a volume of effluent and heating the sample until all of the water is evaporated. For example, a one-liter sample of influent is collected and is heated to evaporate all of the water. The remaining solids weigh 1,000 milligrams. This is total solids (residue), which concentration in the 1liter sample is 1,000 milligrams per liter (mg/L).

3.3.4.2 Dissolved Solids

Dissolved solids, also called filterable residue, are those solids that will pass through a very fine (0.45-micrometer [μm]) membrane filter. To determine dissolved solids, a sample of raw wastewater (a one-liter sample to continue the example above) is collected and filtered through a very fine mesh filter, such as a fiberglass filter. The dissolved solids will pass through with the water. The sample is then evaporated and residual weighed to determine dissolved solids. In Figure 3-1, the amount of dissolved solids is 800 mg/L.

Removal of dissolved inorganic solids from wastewater is difficult to achieve in standard municipal wastewater treatment systems, so concerns with land applying wastewaters that have high concentrations of dissolved solids include: 1) the potential for increased levels of dissolved solids in ground water and 2) the potential for adversely affecting soil properties that are important to land application operations. See Section 3.4.5 for further discussion of TDS and salts.

3.3.4.3 Suspended Solids

Suspended solids, also called nonfilterable residue, are the portion of total solids retained by filtration. Suspended solids (SS) can be removed from a wastewater stream by physical, biological, and/or chemical processes. These solids are classified as either settleable or nonsettleable (colloidal), depending upon their size, shape, and density (weight per unit volume). Larger particles tend to settle more rapidly than smaller particles. In Figure 3-1, the suspended solids concentration is 200 mg/L.

The amount of settleable solids in the raw wastewater is an important factor for the design of settling basins, sludge pumps, and sludge handling facilities. Also, measuring the amount of settleable solids entering and leaving a treatment unit allows the operator to calculate the efficiency of the treatment unit for removing the settleable solids. When a device called an Imhoff cone is used to measure settleable solids, the results are expressed in milliliters per liter (ml/L). In Figure 3-1, the settleable solids concentration is 130 mg/L. The concentration of nonsettleable solids is 70 mg/L. The weight of nonsettleable solids can be calculated by using Equation 3-1.

$$\text{Weight of nonsettleable Solids} = \text{Weight of Total Solids} - \text{Weight of Dissolved Solids} - \text{Weight of Settleable Solids}$$

Equation 3-1. Calculation for weight of nonsettleable solids.

3.3.4.4 Total Suspended Solids (TSS)

The total suspended solids content of wastewater may include organic or inorganic particulate matter, with most of the organic solids being volatile. Many of the concerns related to the chemical oxygen demand of the wastewater and related problems with loading rates apply to total suspended solids, as discussed further in Section 4.2.2.1.

3.4 Wastewater Chemical and Biological Characteristics

Important wastewater characteristics addressed in this section include pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrogen, salts, metals, persistent organic chemicals, phosphorus, and pathogenic organisms. Hazardous materials are discussed in Section 4.2.2.8

3.4.1 pH

The measure of the concentration of the hydrogen ions (H^+) in a solution is called pH. Specifically, pH is the negative logarithm of the hydrogen ion concentration expressed in milliequivalents/liter. A pH of 7 is neutral, while a pH reading below 7 indicates acidic conditions and a pH reading above 7 indicates alkaline (basic) conditions. Acidity is the capacity of wastewater to neutralize bases. Wastewater does not have to be strongly acidic (low pH) to have a high acidity. Alkalinity is the capacity of wastewater to neutralize acids. Wastewater does not have to be strongly basic (high pH) to have a high alkalinity

The pH of domestic wastewater typically ranges from 6.5 to 7.5, depending on the pH of potable water in the service system. Significant departures from these values may indicate industrial or other non-domestic discharges.

In land application systems, bacteria may perform wastewater treatment in pretreatment units and in the soil. These bacteria prefer a neutral pH for best performance. Any rapid increase or decrease in pH can cause mortality in the bacteria population, resulting in poor treatment.

3.4.2 Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen dissolved in water and is usually expressed in milligrams per liter (mg/L). Although some microorganisms can survive in anaerobic conditions (without oxygen), many of the beneficial microorganisms that stabilize wastewater require aerobic conditions (with oxygen).

The amount of oxygen that can be dissolved in water is dependent on temperature—as water temperature increases, dissolved oxygen content decreases and vice versa—and the distribution of oxygen within a lagoon will determine whether the treatment processes involved are aerobic or anaerobic. Maintaining adequate oxygen levels allows aerobic biological process to take place and prevents objectionable odors. Low DO concentrations (less than 1.0 mg/L) can indicate inadequate aeration or an excessive amount of organic material entering the system. Dissolved oxygen is measured using an oxygen meter and a membrane-covered probe. Probes require careful cleaning and meters must be calibrated routinely to ensure accuracy.

3.4.3 Biochemical and Chemical Oxygen Demand

Biochemical oxygen demand (BOD) is the rate at which organisms use oxygen to stabilize or break down the organic matter in wastewater. High levels of BOD indicate high levels of organic matter in wastewater. The typical range of BOD in domestic wastewater ranges from 100 to 300 mg/L of BOD.

BOD is measured using a biochemical oxygen demand test, a procedure that measures the amount of oxygen used by a wastewater sample incubated at 20^{o}C for five days. The amount of organic material measured is referred to as BOD_5, referring to the five day length of the test.

The chemical oxygen demand (COD) analysis estimates the amount of organic matter in wastewater in only three to four hours, rather than the five days required for the BOD_5 test, and can be used as an alternative. The COD test measures the oxygen equivalent (in mg/L) of the materials present in the wastewater by oxidizing the wastewater using a strong chemical oxidant. Because the chemical oxidant may react with substances that cannot be broken down by bacteria, COD results are not directly related to BOD_5. However, COD can be used as a means of rapidly estimating the BOD_5 of a sample if BOD_5-to-COD ratios are developed for a particular system.

COD results are typically higher than BOD_5 values, and the ratio between the two will vary from system to system. The BOD_5-to-COD ratio is typically 0.5:1 for raw domestic wastewater and may drop to as low as 0.1:1 for a well-stabilized secondary effluent.

3.4.4 Nitrogen

Nitrogen in the wastewater effluent can be found in both inorganic and organic forms. Inorganic forms include ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-). In raw wastewater, organic nitrogen and ammonia levels are generally higher than nitrite and nitrate levels. Organic nitrogen includes such natural materials as proteins and peptides, nucleic acids and urea, and numerous synthetic organic materials. Total nitrogen is the sum of organic nitrogen, ammonia, nitrite and nitrate. Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen and ammonia. Typical ranges of nitrogen concentrations in raw domestic wastewater are 20 to 85 mg/L for total nitrogen, 8 to 35 mg/L for organic nitrogen, and 12 to 50 mg/L for ammonia. Plant available nitrogen (PAN) is nitrogen that exists in forms (NH_4^+ and NO_3^-) that are readily available for uptake by plants.

3.4.5 Salts

Chloride, sulfate, carbonate//bicarbonate, potassium, calcium, sodium and magnesium are common soluble salts (ionic species) that are present in wastewater. Some of the salts may be removed during wastewater treatment prior to effluent irrigation. Other salts, such as ferric chloride and alum, are sometimes added to aid in wastewater treatment by precipitating waste constituents.

Salts in wastewater are measured in a variety of ways. Summing individual ions gives what is often called total inorganic dissolved solids (TDIS). As discussed in Section 7.2.4.1.2, the analysis for total dissolved solids (TDS) measures dissolved solids, including organic as well as inorganic (salt) constituents. So in municipal, and particularly industrial, wastewaters, TDS may not represent the salt content of the wastewater. Non-volatile dissolved solids (NVDS) can be used as a rough estimate of salt content. NVDS is calculated according to Equation 3-2:

$$NVDS = TDS - VDS$$

Equation 3-2. Calculation of non-volatile dissolved solids.

Where VDS is volatile dissolved solids (solids which are incinerated upon heating). Total fixed solids (TFS) are the inorganic solids from the total solids of wastewater and better represents inorganic solids content of wastewater.

3.4.6 Metals

Metals are inorganic chemical elements that are present in varying amounts in most waste streams. Although some metals are essential for proper human and plant nutrition, over time they can accumulate in soils and become toxic to plants, humans, and animals.

Metals of concern include cadmium, copper, lead, nickel, zinc, selenium, arsenic, mercury, and molybdenum. Cadmium, arsenic, chromium, and mercury are extremely toxic; nickel, molybdenum, and lead are moderately toxic; and copper, manganese, and zinc are relatively low in toxicity.

Concentrations of metals will vary with the type of wastewater. A typical domestic wastewater has low concentrations of metals, but an industrial wastewater may be very high in metal concentration. Removal of metals from wastewater normally occurs through sludge generation during initial treatment. For example, effluent from domestic sewage contains very small concentrations of the most toxic metals such as cadmium after treatment and sludge separation.

3.4.7 Persistent Organic Chemicals

Microorganisms can readily decompose most organic wastes. There are some organic chemicals of concern which are not readily biodegradable and can persist in the environment for many years. Persistent organic chemicals of concern are generally anthropogenic (man-made) and have the potential to contaminate soils and ground water. They can also be toxic to animals and humans. Like other contaminants, POCs can reach the soil, and from there to ground water, in many ways. They are sometimes a component of pesticides (insecticides and herbicides), or they may be found in the waste stream that is being treated at the land application site. Persistent organic chemicals are also found where old underground storage tanks have leaked petroleum products into the soil.

With a municipal or domestic waste source, persistent organic chemical concentrations are likely to be extremely low, or nonexistent. These chemicals may be present in higher concentrations, however, in an industrial waste source.

3.4.8 Phosphorus

Certain wastewater land treatment facilities, industrial facilities in particular, may generate appreciable quantities of phosphorus in wastewater streams. Many of these facilities have opted to land treat their wastewater. Since there are unique environmental considerations with respect to treatment of these wastewater streams, it is important to provide additional guidance to promote appropriate design, implementation and successful operation of these land treatment facilities. See Section 4.2.2.7 for further discussion of phosphorus.

3.4.9 Pathogenic Organisms

Microorganisms can live and reproduce when there is substrate (food), appropriate temperatures, water, and time. Both municipal (sanitary) and industrial wastewaters can have significant microbial populations. Food processing wastewaters in particular are rich in substrate, and can have significant populations of microorganisms. Wastewaters resulting from the washing of harvested crops can have great numbers of non-enteric and non-pathogenic soil microorganisms, including coliform bacteria and other organisms ubiquitous in the soil environment. Other wastewaters such as cheese processing wastewaters can have pathogenic organisms including certain species of salmonella and lysteria. Where industrial wasterwaters are stored, water fowl and other animals can deposit fecal material and thus contribute to non-human enteric pathogen populations such as certain species of streptococcus.

Raw sanitary wastewater also has significant populations of microorganisms . Most of these are not harmful to humans, and some of them are helpful in wastewater treatment processes. However, humans and warm-blooded animals with diseases caused by bacteria or viruses may discharge some of these harmful organisms in their body wastes (fecal wastes), and many serious outbreaks of communicable diseases have been traced to direct contamination of drinking water or food supplies by the body wastes from a human disease carrier.

Disease-causing microorganisms (pathogens) include bacteria, viruses, parasitic protozoa and helminths (worms). Some known examples of diseases that may be spread through wastewater discharges are typhoid, cholera, shingellosis, dysentery, polio, and hepatitis. Fortunately, the bacteria that grow in the intestinal tract of diseased humans and warm-blooded animals are not likely to find the environment in a wastewater treatment system favorable for their growth and reproduction.

3.4.9.1 Identification of Pathogens

It is impractical to test wastewater for all pathogens. Instead, indicator bacteria organisms are commonly used to indicate fecal contamination and the possible presence of pathogens in sanitary wastewater. One commonly used indicator is total coliform bacteria, a group of bacteria that are easily identified through laboratory tests. Total coliform bacteria are always present in the digestive systems of humans and warm-blooded animals. If there is a large concentration of coliform bacteria present in wastewater, the potential for the presence of pathogens is high. The Idaho Department of Environmental Quality (DEQ) uses total coliform bacteria as the indicator of potential pathogen levels in land-applied wastewater. Regulatory requirements for treatment and microbiological quality, as well as allowed uses for wastewater classifications are found in IDAPA 58.01.17.600.07 and 08, respectively.

3.4.9.2 Removal of Pathogens

The removal of microorganisms, particularly human pathogens, from sanitary wastewater is an important consideration in land treatment. Wastewater treatment processes remove pathogenic organisms in several ways: physical removal through filtration and sedimentation, natural die-off of organisms because of unfavorable environments, and destruction of organisms by disinfection.

Extensive field observations indicate that bacteria and viruses are removed from wastewater as it moves through the soil. Removal of microorganisms is accomplished initially by filtration and adsorption. Because of their large size, helminths and protozoa are removed primarily by filtration at the soil surface. Bacteria can be removed by filtration in the soil as well as by adsorption. Coliform removal in the soil profile has been shown to be approximately the same when primary or secondary pre-treatment is provided prior to land application. Unless fissures, dissolution channels, or macropores are present for hastened downward movement of organisms, soil will remove bacteria and viruses within several inches or at most a few feet. Fecal coliforms are normally absent after wastewater percolates through five feet of soil. Viruses are removed primarily by adsorption.

After filtration and adsorption, the organisms then die due to radiation, desiccation, predation by other indigenous microorganisms, and exposure to the adverse conditions in the soil. It is not expected that the presence of microorganisms in wastewater will be a limiting factor once wastewater has entered the soil, with the exception of animal grazing. See Section 6.4 for further discussion on grazing management.

The residual concentration of microorganisms in treated wastewater is variable depending on several factors including type of wastewater, the efficiency and degree of disinfection (typically chlorination or ozonation), substrate concentration in wastewater, storage temperature and length of storage. The greater resistance of viruses to most disinfection procedures and the possibility of chlorination breakdown increases the importance of the ability of the soil to remove organisms.

Although many pathogenic organisms are killed (called natural die-off) during the normal treatment processes, sufficient numbers can remain in the effluent (wastewater leaving the treatment system) to cause a threat to any downstream use involving human contact if adequate disinfection is not accomplished in the treatment process.

3.4.9.3 Microbial Risk Analysis and Land Treatment

To help minimize the exposure of human receptors to microorganisms from land treatment system operations, land application methods should be conducted to minimize aerosol drift off site. Section 6.5 should be consulted for tables of microbial wastewater quality and buffer zone requirements.

DEQ is in the process of developing preliminary methodologies for assessing risk from microorganisms at wastewater land treatment sites. This interim effort is described in the following document - *Technical Background Document: Microbial Risk Assessment and Fate and Transport Modeling of Aerosolized Microorganisms: Recommendations at Wastewater Land Application Facilities in Idaho* (DEQ, 2006). This document provides technical and scientific background necessary for making quantitative assessments of risk to human health from microbial constituents in municipal and industrial wastewaters that are land applied. Both municipal and food processing wastewaters in Idaho contain various microbial constituents, which may have the potential to pose a risk to human health.

To evaluate the relative risk of different land application practices, a quantitative microbial risk assessment methodology has been developed that uses microbial densities in air as critical input. The airborne transport pathway involves wastewater aerosolization, dispersion, deposition, and die-off. Irrigation droplet drift and aerosol transport are accounted for to predict microbial densities in air and deposited on surfaces downwind. The fate and transport approach is largely based on early EPA work (1982), with improvements made in aerosolization and dispersion/deposition modeling and in using the results to address human health impacts.

A methodology has also been developed to provide an estimate of risk to public health given modeled microbial densities, type of receptor, mode of entry (ingestion or inhalation), and microorganism-specific characteristics. Preliminary model results suggest that drift and deposition of fine droplets at higher wind speeds may contribute to the risk of infection through ingestion of produce, a pathway not considered in the 1982 EPA guidance.

3.4.10 Pharmaceuticals and Personal Care Products (PPCPs)

The significance of Pharmaceuticals and Personal Care Products (PPCPs) on humans and the environment is an emerging issue to which much research is being devoted. Research on occurrence and potential effects of PPCPs in Europe has been ongoing since the 1980s. PPCPs did not receive much interest in the U.S. until the late 1990s.

PPCPs include all human and veterinary drugs, diagnostic agents, and nutraceuticals (bioactive food supplements). It also includes chemicals such as caffeine, nicotine and aspirin which have been known to be present in surface water at least since the 1970s. Several classes of PPCPs have been identified in environmental samples, including: analgesic/anti-inflammatory drugs, antiseptics/fungicides, lipid regulators, X-ray contrast media, psychiatric drugs, beta-blockers, antineoplastic drugs, contraceptives, antibiotics, antiepileptics, antidepressants, bronchodilators, antihypertensives, sunscreens, and synthetic musks.

Major concerns regarding PPCPs are pathogen resistance to antibiotics and disruption of endocrine systems by natural and synthetic sex steroids, particularly in aquatic organisms. Antidepressants (selective serotonin uptake inhibitors) and calcium channel blockers are also of potential concern for effects on aquatic life. The effects of chronic exposure to complex mixtures of PPCPs at very low concentrations has not been well-studied. Effects on aquatic organisms such as feminization of male fish have been documented at very low (ppt) concentrations of endocrine disrupting compounds (EDCs). The potential for adverse human health effects is currently unknown.

PPCPs are entering the environment primarily from end-use rather than manufacturing. PPCPs come from municipal wastewater, hospital wastewater, and veterinary drugs used at both confined animal feeding operations (CAFOs) and in aquaculture.

There are several effects of wastewater treatment on PPCPs. Degradation of PPCPs in municipal sewage treatment facilities is a function of both treatment technology and the chemical's structure. Some free excreted drugs and metabolites are not degraded during treatment. Conjugates can be hydrolyzed back to the parent drug. Biologically active PPCPs in treated wastewater are discharged to surface water. They can reach ground water through leaching or recharge.

3.5 References

Idaho Department of Environmental Quality, 2006. Rules for the Reclamation and Reuse of Municipal and Industrial Wastewater (IDAPA 58.01.17).

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Environmental Protection Agency [EPA]. May 1982. Estimating Microorganism Densities in Aerosols from Spray Irrigation of Wastewater. EPA 600/9-82-003. USEPA, Washington, DC. 32 pages.

U.S. Environmental Protection Agency [EPA]. 2004. Operation of Wastewater Treatment Plants.